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AN EXPERIMENTAL INVESTIGATION OF PRESSURE ATTENUATION IN TYPICAL MISSILE PLUMBING SYSTEMS SUBJECTED TO SHOCK WAVE INPUTS--PART II

A THESIS

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AN EXPERIMENTAL INVESTIGATION OF PRESSURE ATTENUATION IN TYPICAL MISSILE PLUMBING SYSTEMS SUBJECTED TO SHOCK WAVE INPUTS--PART II

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Approved:

Arnold L. Ducoffe

Robin B. Gray

Charles W. Gorton

Date Approved by Chairman:

June 2, 1958

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

C	empirical factor
D	line inside diameter, inches
D_F	fitting inside diameter, inches
K	empirical factor
L	line length, feet
L/D	ratio of line length to line inside diameter
M	empirical factor
N	empirical factor
P_I	input pressure, pounds per square inch gauge
P_R	response pressure, pounds per square inch gauge
R_D	diameter ratio, D_F/D
S	empirical factor

Subscripts

1	indicates line inside diameter of 0.370 inches
2	indicates line inside diameter of 0.242 inches

SUMMARY

This report is the result of an experimental investigation conducted to determine the pressure attenuation occurring in a system of tubing, fittings, and volumes representative of the type used in missile baro-sensing units when subjected to shock wave inputs. A shock wave was generated by the use of a shock tube with a two-inch diameter straight nozzle open to the atmosphere. The wave so formed was sampled by a test system consisting of a small bore tube having variable diameter fittings upstream and downstream, and a 10.51 cubic inch closed volume at the downstream end. Transducers at the entrance and volume end of the test geometry sensed the transient pressures across the wave, and after the transducer outputs were amplified, they were recorded by a multi-channeled recording oscillograph. Data was taken with shock tube pressures ranging from 50 to 1,000 pounds per square inch gauge and with the following ranges in the variation of geometry: (1) line lengths of 1, 5, 10, and 15 feet; (2) line inside diameters of 0.370 and 0.242 inches and (3) fitting inside diameters from 50 to 100 percent of line inside diameters.

It was concluded from the experimental data that, except for input pressures under 100 pounds per square inch gauge, the pressure attenuation in the systems tested does appear to be sufficient to protect a missile baro-sensing system from damage or destruction. It was found that decreasing line diameters produced the greatest attenuation in the response pressures, with decreasing fitting diameters

having the second greatest effect and increasing line lengths the smallest effect.

Four empirical equations relating the maximum response pressures to the maximum input pressures were derived from the experimental data. Two equations are applicable to each of two ranges of input pressures, from 40 to 300 pounds per square inch gauge and from 300 to 900 pounds per square inch gauge. The equations are limited to the ranges of the test variables.

CHAPTER I

INTRODUCTION

Many large modern missiles are equipped with some type of barometric pressure sensing system. This equipment may be used only for the purpose of recording the variations in the external air pressure along the missile's trajectory, or the same equipment may be put to the more elaborate use of arming and detonating a warhead at a set altitude during the terminal part of its trajectory.

Much work has already been done to establish the effects of the various plumbing components in a baro-sensing system on pressure attenuation and lag for the low pressure regime, that is, for pressures of one-half to three atmospheres. There is, however, a lack of this information for pressures higher than three atmospheres.

The advent of the anti-missile missile would make it necessary to know the effect of plumbing components on the attenuation of the high pressures associated with blast waves. A near miss with an anti-missile device would destroy the sensing unit or detonate a warhead prematurely if the losses in the plumbing were not sufficiently large or if a protective valve or by-pass arrangement was not incorporated.

The purpose of this experimental research is to investigate the effects of the variable plumbing components, especially fitting diameters, on the over-pressure attenuation in a simulated missile baro-sensing system with shock wave inputs. This is done by presenting information determined experimentally relating combinations of fitting diameters (D_F), and tube lengths (L), to response pressures (P_R) for various strength waves or input pressures (P_I). The investigation is limited to straight through fittings and lines, and input pressures ranging from approximately 40 psig to 900 psig. Empirical relationships were determined from the experimental data and are also presented.

CHAPTER II

APPARATUS

A detailed description of the test apparatus can be found in reference 1. However, a brief description of the equipment and the details of necessary modifications will be included.

The major components of the apparatus used in this investigation were as follows: an engine driven compressor and storage tank, a control board, a shock tube, the system of plumbing to be tested, and the instrumentation for measuring and recording the transient pressures.

The compressor, an Ingersoll-Rand four stage high pressure compressor, Model GC-50-BW, was driven by a Waukesha six cylinder gasoline engine.

Air at high pressure (1300 psig) was fed from the storage tank to the control board through 0.25 inch copper tubing. On the board were mounted two gauges and several valves, so that air could either be made available for charging the shock tube or for pressurizing the test system while it was checked for leaks and the instrumentation was calibrated. The first of the gauges had a range and accuracy of 0-3000$\pm$5 psig and was used to monitor the pressure of the air charge to the shock tube and the pressures applied to the transducers during calibrations.

The shock tube was a 7.625 foot length of four inch diameter steel pipe with extra heavy walls. One end was closed by a steel plate bolted in position with 0.25 inch copper tubing attached for charging the tube. Fastened to the other end of the shock tube was a heavy steel body with a two inch diameter opening, to which was bolted a two inch diameter straight nozzle. Closure of this end resulted when a sandwich of several thicknesses of Mylar Polyester Film and a small diameter steel wire were placed between the nozzle and the shock tube. The wire was the triggering mechanism, which, when heated by a low voltage (28 volts), weakened the plastic diaphragm material and caused it to rupture. The shock tube and nozzle were rigidly mounted to a heavy wooden table, and the table was shock mounted on a concrete pad.

The system of plumbing to be tested was mounted on a step in the concrete pad by means of an adjustable mount and a vertical mounting plate. It consisted of a pickup tube (0.56 inch inside diameter), an upstream fitting, the test line, a downstream fitting, and a 10.51 cubic inch volume. The general layout of the shock tube and test system is shown in Fig. 1.

The test lines were steel tubing flared for 37° fittings in lengths of 1, 5, 10, and 15 feet. Two line diameters were tested with inside diameters of 0.370 inches and 0.242 inches. Two Parker No. 8HBTX-S fittings were used for the 0.370 inch diameter lines, and two Parker No. 5HBTX fittings were used for the 0.242 inch diameter lines. These fittings were modified so that they would accept inserts. The No. 8 fittings were bored to a nominal inside diameter of 15/32 inches, and the No. 5 fittings were bored to an inside diameter of 21/64 inches. The flared ends were machined off both sizes of fittings. The bore size was not critical. The only considerations were that the

Fig. 1 General Layout of Test Apparatus

fittings retain their strength at the threads and that the inserts have walls of sufficient thickness so that deformation would not occur. The inserts were made to fit the modified fittings in diameter and length, and were machined to mate with 37° flared tubing. The details of a typical fitting installation are shown in Fig. 2. The inside diameters of the inserts ranged from 50 to 100 percent of line diameter and are listed with their associated line diameter in Table 1.

Two Statham Temperature Compensated Pressure Transducers (0-1000 psig, Model No. PG 10TCa-1M-350) were attached to the test system by flexible tubing to reduce mechanical vibrations. The upstream transducer sensed the transient pressure at a port in the pickup tube approximately two inches upstream of the fitting. The downstream transducer sensed the transient pressure at a port in the volume. Linear amplifications of the transducer outputs were accomplished by an Oscillator-Power Supply Combination, Type 2-105A, and two Bridge Amplifiers, Type 1-113B. A Consolidated Recording Oscillograph, Type 5-114, and two single trace Sanborn Recorders received and recorded the amplified transducer outputs. Although the response of the Sanborn Recorders was quite low, approximately 90 cycles per second, they yielded immediate data for qualitative examination, while the Oscillograph records had to be developed before the data was available. The galvanometers installed in the Oscillograph were equivalent to Consolidated Galvanometers, Type 7-223. Their response characteristics, 500 cycles per second, established the maximum response for the instrumentation.

Note: Parker Fittings No. 8 HBTX-5 for 0.370 in. Line I.D.

Parker Fittings No. 5 HBTX for 0.242 in. Line I.D.

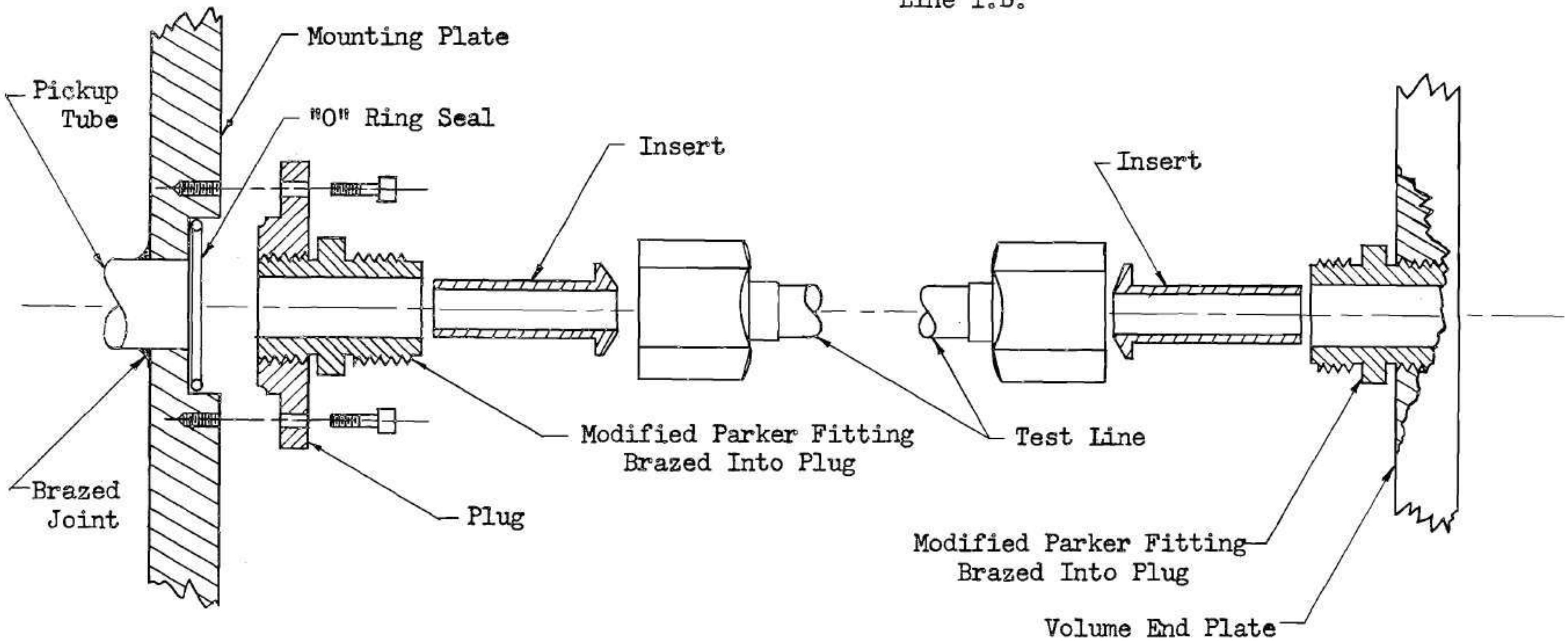

Fig. 2 Typical Fitting Installation

Table 1. Line Diameters and Associated

Fitting Diameters Tested

Line Diameter, D--0.370 inches

Fitting Diameter, D_F (inches)	Diameter Ratio, R_D
0.370	1.000
0.325	0.878
0.230	0.622
0.185	0.500

Line Diameter, D--0.242 inches

Fitting Diameter, D_F (inches)	Diameter Ratio, R_D
0.242	1.000
0.216	0.893
0.168	0.694
0.123	0.508

CHAPTER III

PROCEDURE

All experimental work was conducted outdoors at Georgia Institute of Technology, Research Area #2.

The details for the procedure used in obtaining experimental data are given by DeJarnette (1). However, additional runs were necessary to investigate the effect of fitting diameter. Each fitting diameter was tested with each line length and with shock tube pressures of 50, 100, 200, 700, and 1,000 psig.

CHAPTER IV

RESULTS

The procedure used to reduce the experimental data required the reduction of all calibration information to a scale constant for each attenuation setting on the Bridge Amplifiers. The calibration data was read with a millimeter scale to the nearest 0.5 millimeter. The scale factor, with units of pounds per square inch gauge per millimeter, was chosen to be the arithmetic mean value of all calibration data for a particular amplifier attenuation. Deviations in the calibration data were within $\pm$ 2 percent of the mean value. The maximum input pressures, $P_{I\ max}$, and maximum response pressures, $P_{R\ max}$, were also read from the oscillograph records with a millimeter scale to the nearest 0.5 millimeter. These readings, when multiplied by the appropriate scale factor, yielded $P_{I\ max}$ and $P_{R\ max}$ in pounds per square inch guage. This reduction procedure introduced errors in $P_{I\ max}$ and $P_{R\ max}$ no greater than $\pm$ 4 percent. Typical oscillograph record traces are shown in Fig. 3.

When the data was plotted as $P_{R\ max}$ vs. $P_{I\ max}$, it appeared that linear relationships existed between $P_{R\ max}$ and $P_{I\ max}$ up to an input pressure of approximately 300 pounds per square inch gauge; furthermore, it appeared that other linear relationships might also exist for the input pressure range from 300 to 900 pounds per square inch gauge. Straight lines faired through the data points in the lower pressure range passed through the axes origin as a common point of intersection. Straight lines faired through the data points

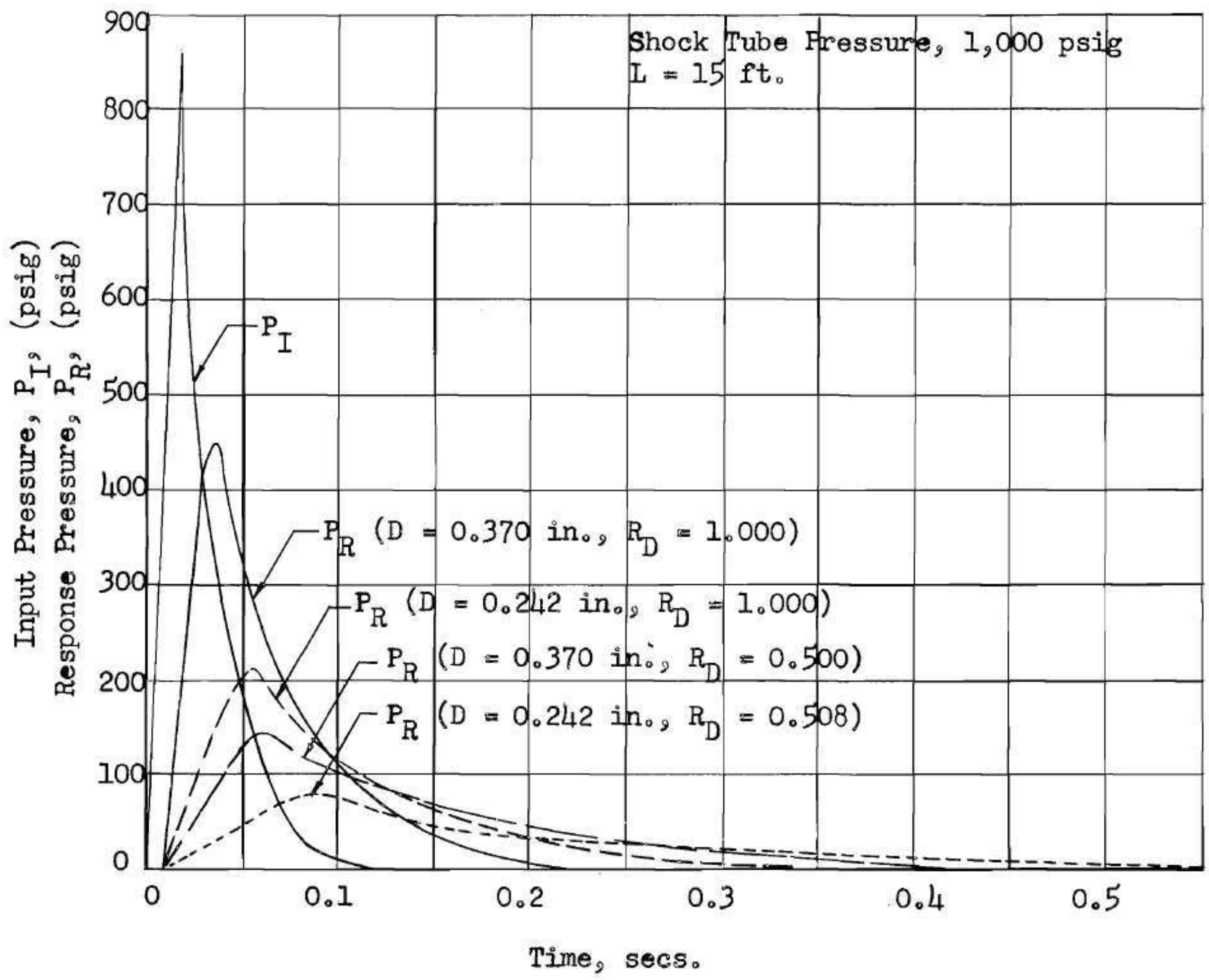

Fig. 3 Typical Oscillograph Records for Different Line Diameters and Different Diameter Ratios

in the higher pressure range also had a common point of intersection which was not at the origin. These common points of intersection were independent of L, D_F, D, and $P_{I\ max}$. These two observations suggest the possibility of two different regimes dependent on the magnitude of the input pressure.

Empirical equations were formulated on the premise that the two linear regimes do exist. Four empirical equations resulted from the analysis. With a line inside diameter of 0.370 inches, for $40 \leq P_{I\ max} \leq 300$ psig,

$$P_{R\ max} = 0.536 \left[6.2 - (L/D)^{1/4}\right]^{1/2} (R_D - 0.15)\ P_{I\ max} \tag{1}$$

and for $300 \leq P_{I\ max} \leq 900$ psig,

$$P_{R\ max} = 0.536 \left[6.1 - (L/D)^{1/4}\right]^{1/2} (R_D - 0.22) \times (P_{I\ max} + 25) + 15 \tag{2}$$

With a line inside diameter of 0.242 inches, for $40 \leq P_{I\ max} \leq 300$ psig,

$$P_{R\ max} = 0.456 \left[3.4 - (L/D)^{1/4}\right]^{1/2} (R_D - 0.20)\ P_{I\ max} \tag{3}$$

and for $300 \leq P_{I\ max} \leq 900$ psig,

$$P_{R\ max} = 0.456 \left[3.3 - (L/D)^{1/4}\right]^{1/2} (R_D - 0.30) \times (P_{I\ max} + 25) + 15 \tag{4}$$

These four relations are limited by the ranges of L, D_F, and $P_{I\ max}$, but are especially restricted by the two line diameters and one downstream volume.

The empirical equations are presented graphically and compared to the experimental data points for line lengths of 1, 5, 10, and 15 feet in Figs. 4, 5, 6, and 7 respectively. It can be seen that agreement is within $\pm$ 4 percent in the low pressure range and within $\pm$ 8 percent in the high pressure range. The details of the empirical analysis are presented in the appendix.

In Fig. 4, the effects of line diameter and fitting diameter appear to be approximately the same, and the response is higher for the 0.242 inch diameter line with 0.242 inch fittings installed (R_D = 1.000) than for the 0.370 inch diameter line with 0.230 inch fittings installed (R_D = 0.622). However, as the line length increases, the effect of line diameter becomes greater than fitting diameter. The effect of line length is less than the effect of line inside diameter or fitting inside diameter in all the configurations tested.

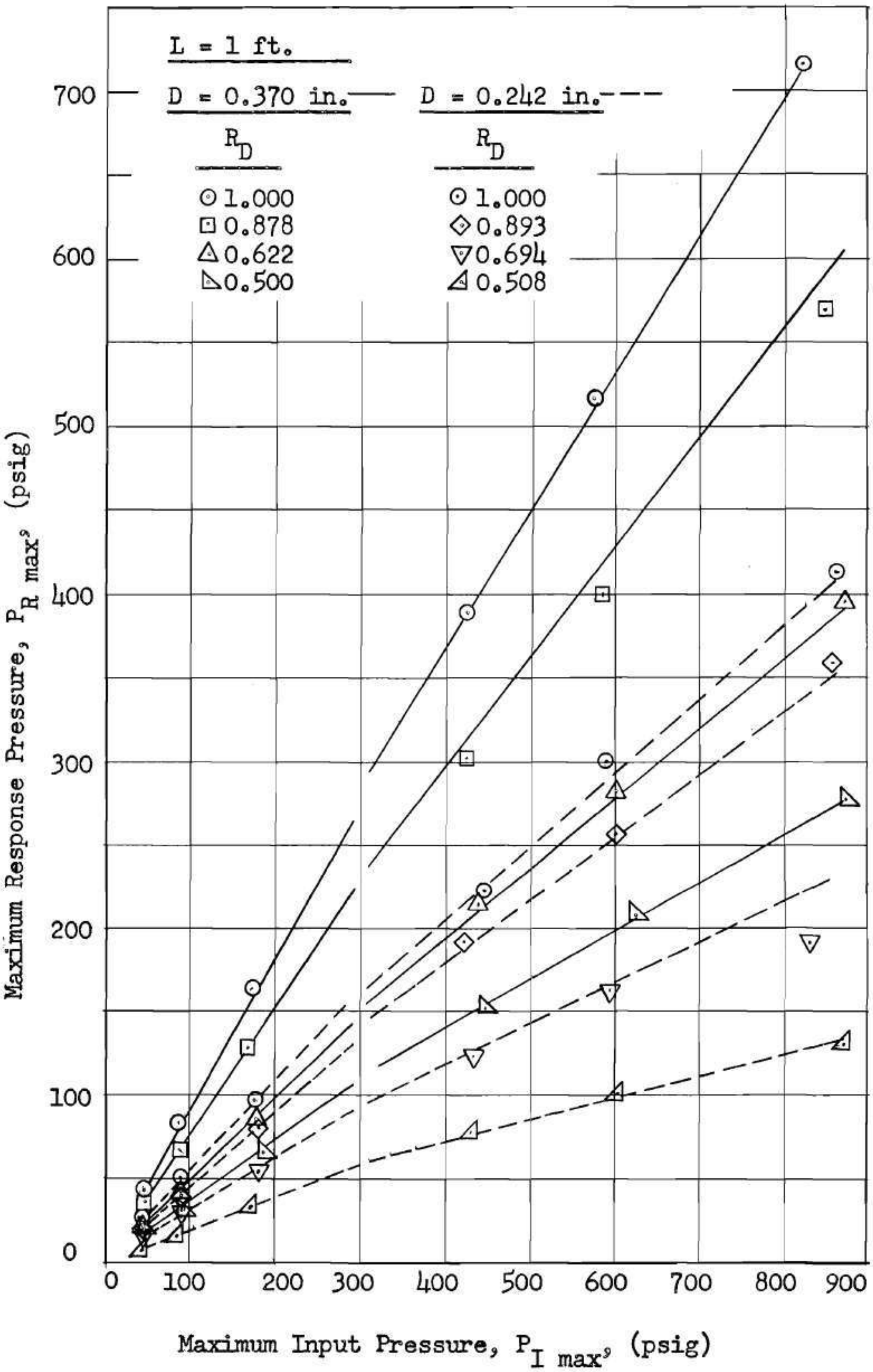

Fig. 4 Comparison of Empirical and Experimental Data

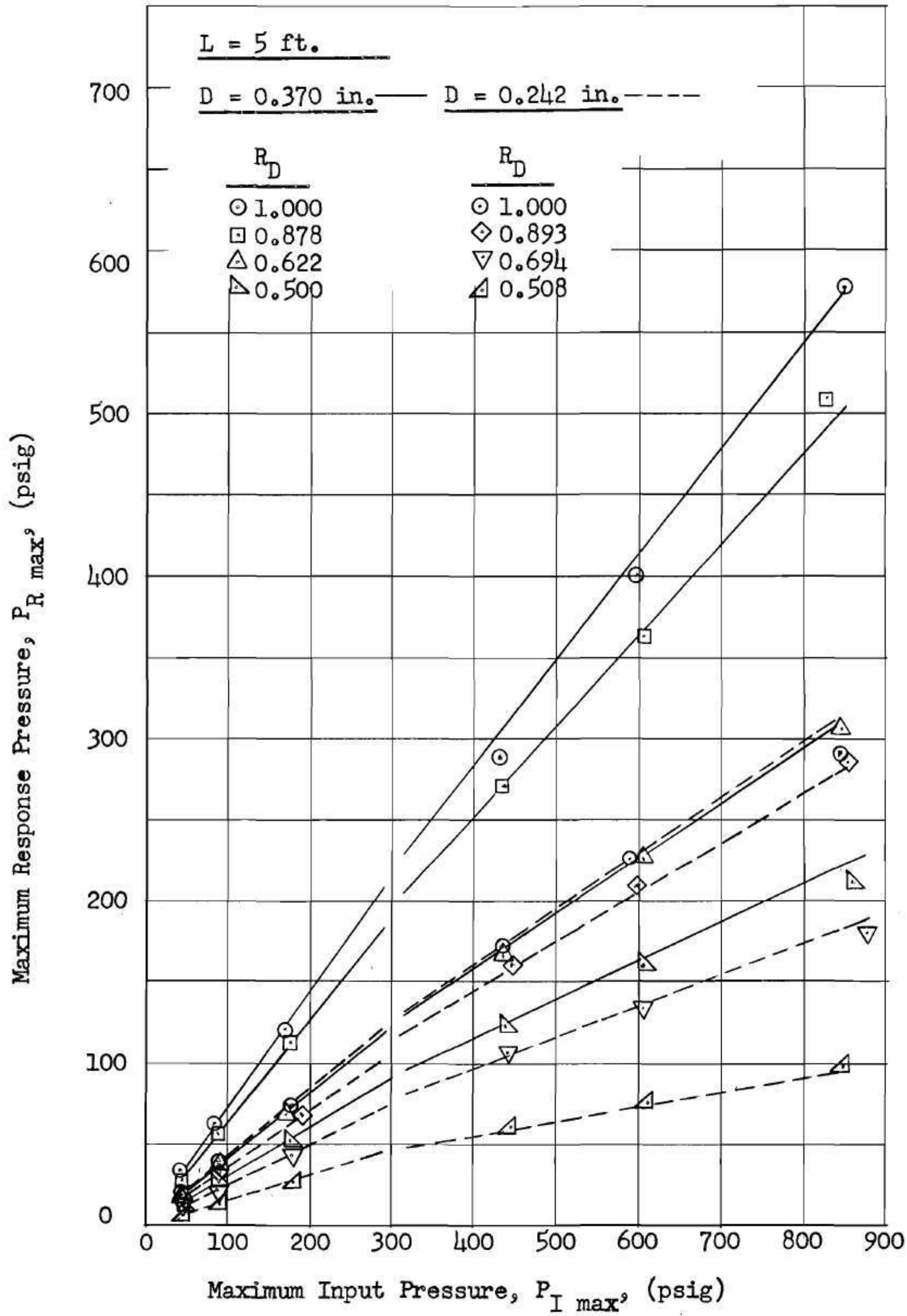

Fig. 5 Comparison of Empirical and Experimental Data

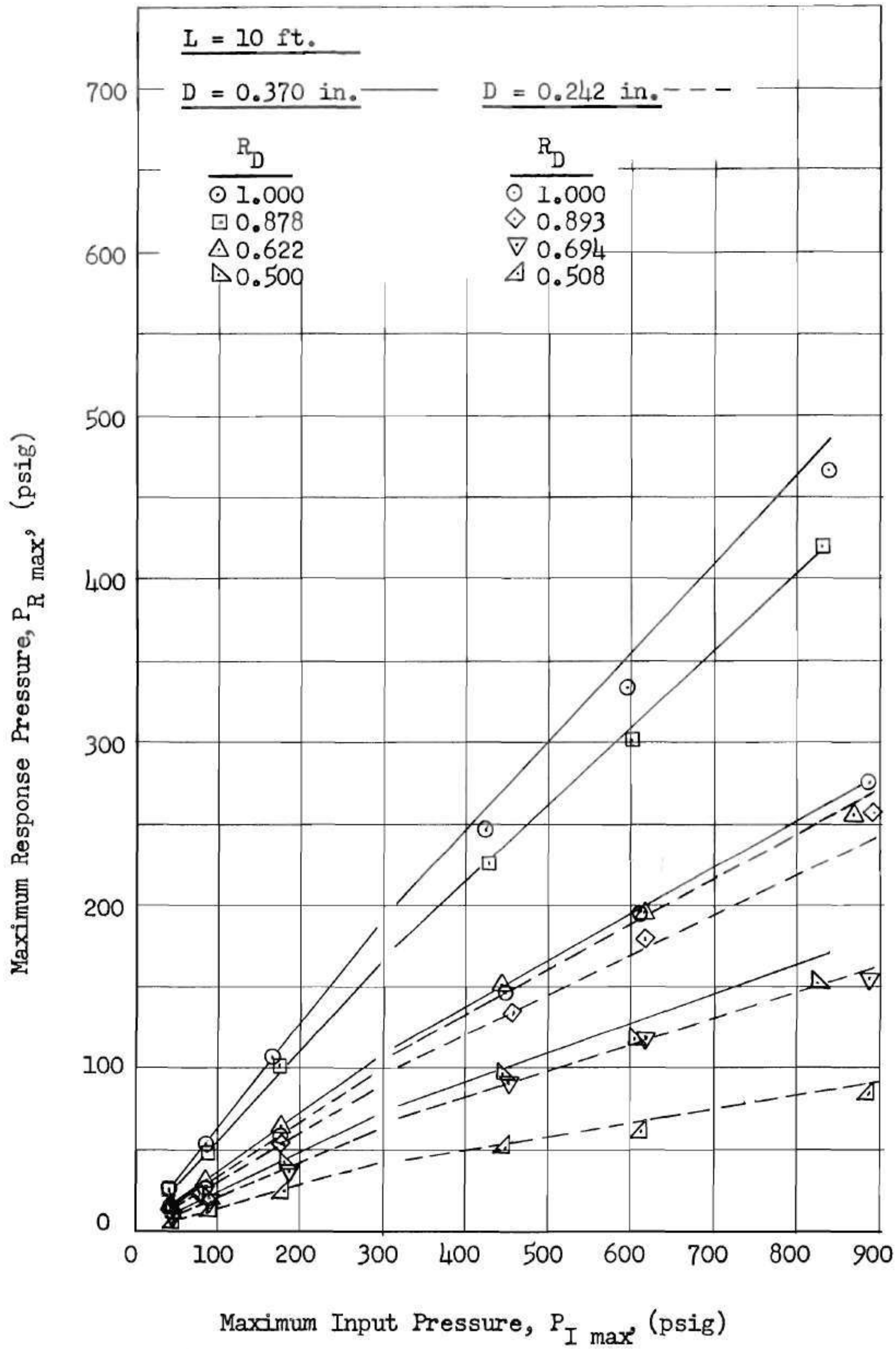

Fig. 6 Comparison of Empirical and Experimental Data

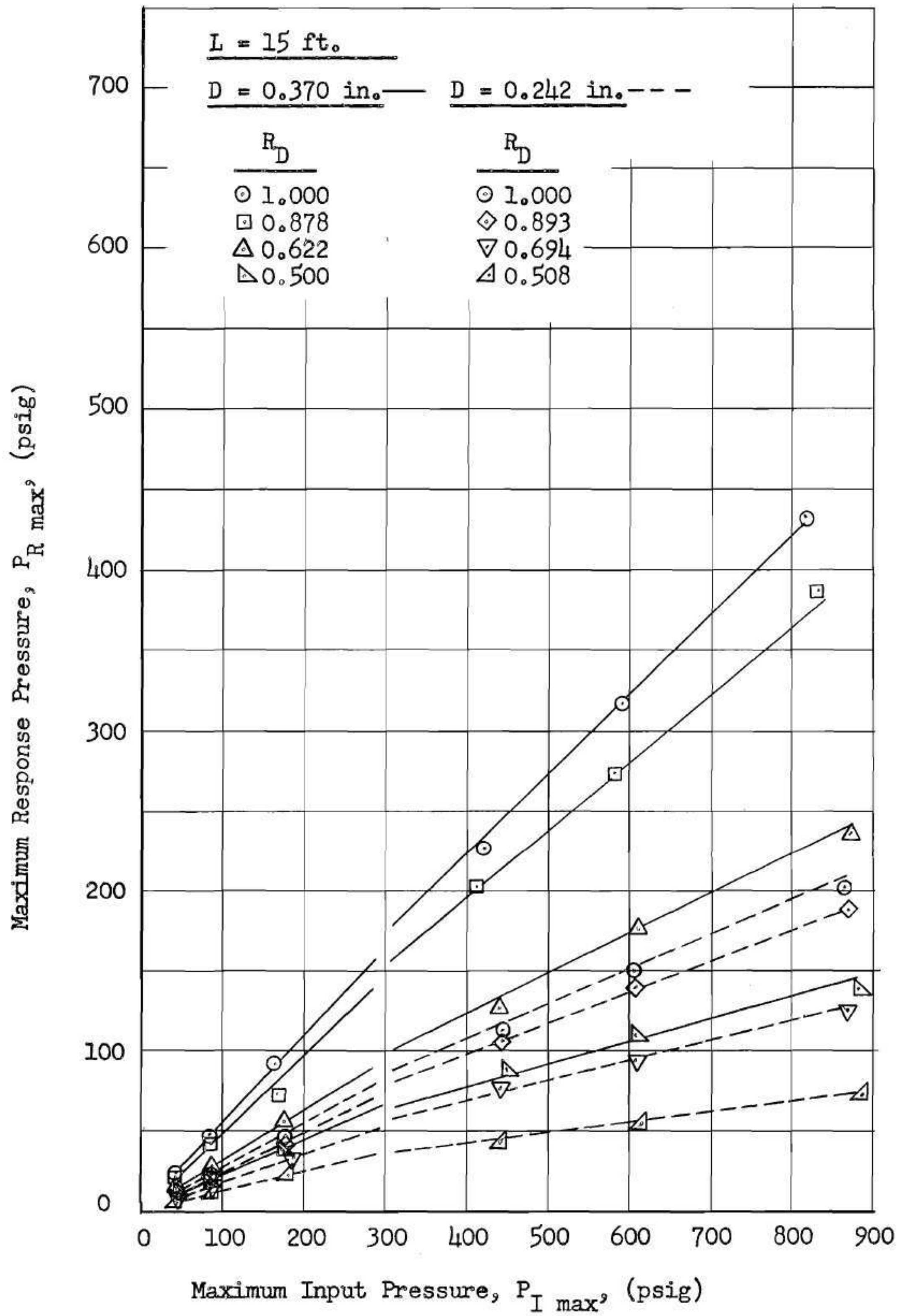

Fig. 7 Comparison of Empirical and Experimental Data

CHAPTER V

CONCLUSIONS

From the data obtained in the investigation, the following conclusions have been reached:

1. Except for input pressures under 100 pounds per square inch gauge, the pressure attenuation in the systems tested does not appear to be sufficient to protect a missile baro-sensing system from damage or destruction.

2. Empirical equations relating $P_{R\ max}$ to $P_{I\ max}$, derived for a fixed downstream volume, line diameters of 0.370 and 0.242 inches and two pressure ranges for $P_{I\ max}$, show good agreement with experimental data. In the low pressure range, $P_{I\ max}$ from 40 to 300 pounds per square inch gauge pressure, the agreement of the empirical data is within $\pm$ 4 percent of the experimental data. In the high pressure range, $P_{I\ max}$ from 300 to 900 pounds per square inch gauge pressure, the agreement of the empirical data is within $\pm$ 8 percent of the experimental data. These equations will apply only within the limits of the ranges of the test variables.

3. The largest effect on the attenuation of the maximum response pressures is produced by decreasing line diameters. For one foot line lengths, the effects of decreasing the line diameters and decreasing the fitting diameters are of approximately the same magnitude. However, for lengths of five feet or more, the effect of line diameter becomes greater than the effect of fitting diameter. The

effect of increasing the line length is smaller than either of the effects of the other two system variables.

CHAPTER VI

RECOMMENDATIONS

Recommendations are as follows:

1. Data still available for reduction from the oscillograph records taken during this program should be studied and presented, perhaps in conjunction with an attempted theoretical analysis. It is believed that a theoretical analysis will lead to non-linear equations and that these equations must be programmed into a digital or analog computer for analysis.

2. Further studies of this nature should be instrumented with direct reading recorders having higher response characteristics. The response could well be as high as 2,000 cycles per second.

3. Similar investigations should be made to include the effects of tube diameters, downstream volumes, elbow and tee fittings, and curved or bent lines.

APPENDIX

APPENDIX

DETAILS OF EMPIRICAL ANALYSIS

Examination of the experimental data showed what appeared to be two linear regimes for $P_{R\ max}$ vs. $P_{I\ max}$. For $P_{I\ max}$ from 40 to approximately 300 psig, straight lines faired through the data points passed through the origin. For $P_{I\ max}$ in the range from 300 to 900 psig, straight lines faired through the data points had a common point of intersection other than the origin. Two equations resulted from this examination.

For $40 \leq P_{I\ max} \leq 300$ psig,

$$P_{R\ max} = K\ P_{I\ max} \tag{5}$$

For $300 \leq P_{I\ max} \leq 900$ psig,

$$P_{R\ max} = C\ (P_{I\ max} + 25) + 15 \tag{6}$$

Values for K and C were dependent on line inside diameter, D, line length, L, and fitting diameter, D_F.

It was then found that K and C were related lineally to the diameter ratio, R_D, for each line diameter, but they were still dependent on line length. The relations are expressed as

$$K_1 = M_1\ (R_{D_1} - 0.15) \tag{7}$$

$$K_2 = M_2\ (R_{D_2} - 0.20) \tag{8}$$

$$C_1 = N_1 \left(R_{D_1} - 0.22\right) \tag{9}$$

$$\text{and } C_2 = N_2 \left(R_{D_2} - 0.30\right) \tag{10}$$

where the subscripts 1 and 2 indicate D = 0.370 inches and D = 0.242 inches respectively. These relationships are shown graphically in Figs. 8 and 9.

Further analysis showed that M and N were related to the line lengths, through L/D, by the equations

$$M_1^{\ 2} = S_1 \left[6.2 - (L/D)_1^{\ 1/4}\right] \tag{11}$$

$$N_1^{\ 2} = S_1 \left[6.1 - (L/D)_1^{\ 1/4}\right] \tag{12}$$

$$M_2^{\ 2} = S_2 \left[3.4 - (L/D)_2^{\ 1/4}\right] \tag{13}$$

$$N_2^{\ 2} = S_2 \left[3.4 - (L/D)_2^{\ 1/4}\right] \tag{14}$$

Values for S_1 and S_2 were determined to be 0.288 and 0.209 respectively. Equations (11), (12), (13), and (14) are presented graphically in Fig. 10.

When equations (7) and (11) were substituted into equation (5), an equation resulted which related L, D_F, $P_{R\ max}$, and $P_{I\ max}$, for $P_{I\ max}$ in the range $40 \leq P_{I\ max} \leq 300$ psig and for a line diameter of 0.370 inches. This is equation (1) found in Chapter IV. Similar substitutions of equations (9) and (12) into (6), (8) and (13) into (5), and (10) and (14) into (6) yielded equations (3), (4), and (5) respectively, also found in Chapter IV.

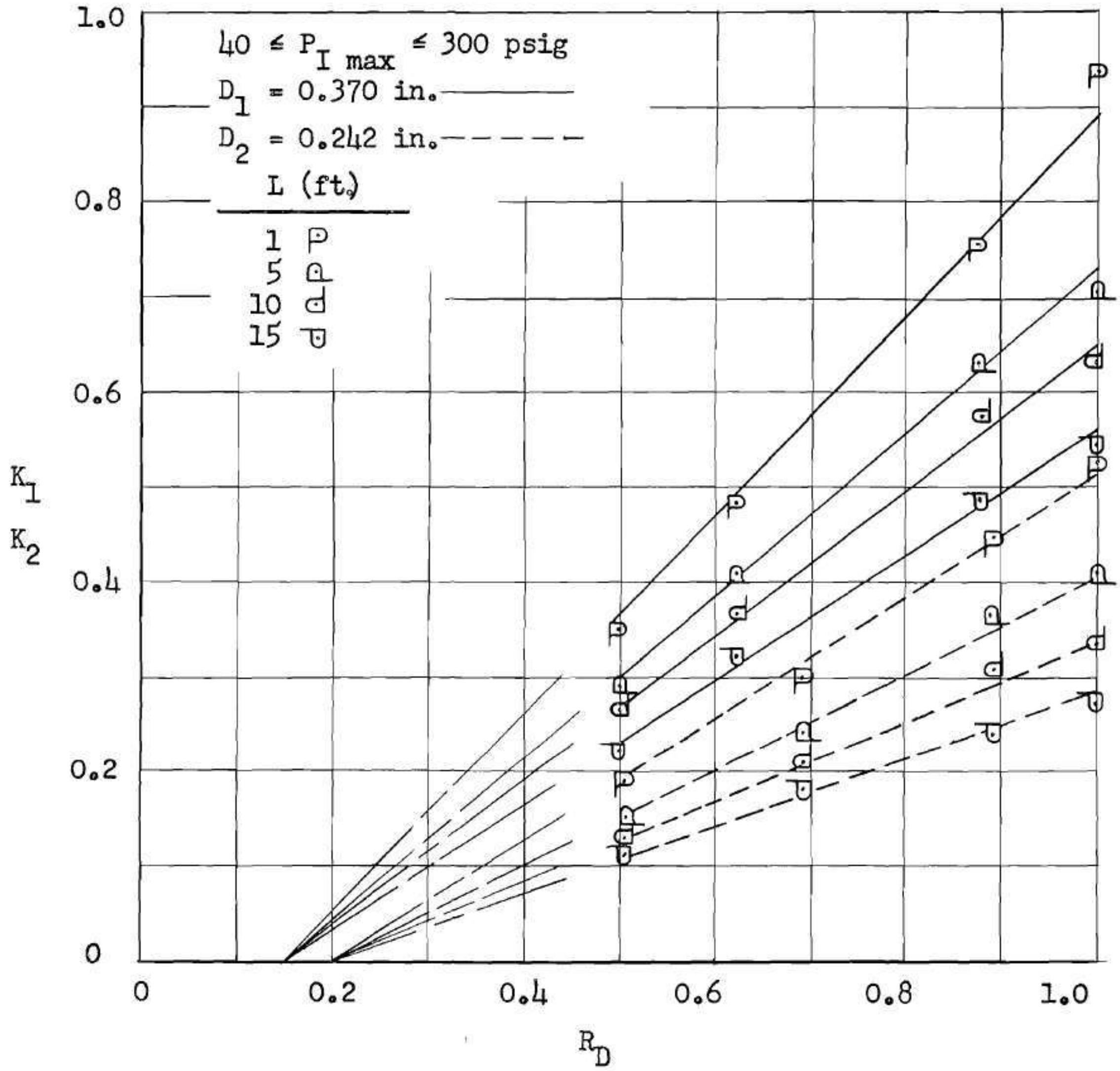

Fig. 8 Relations of Empirical Factors to Diameter Ratios

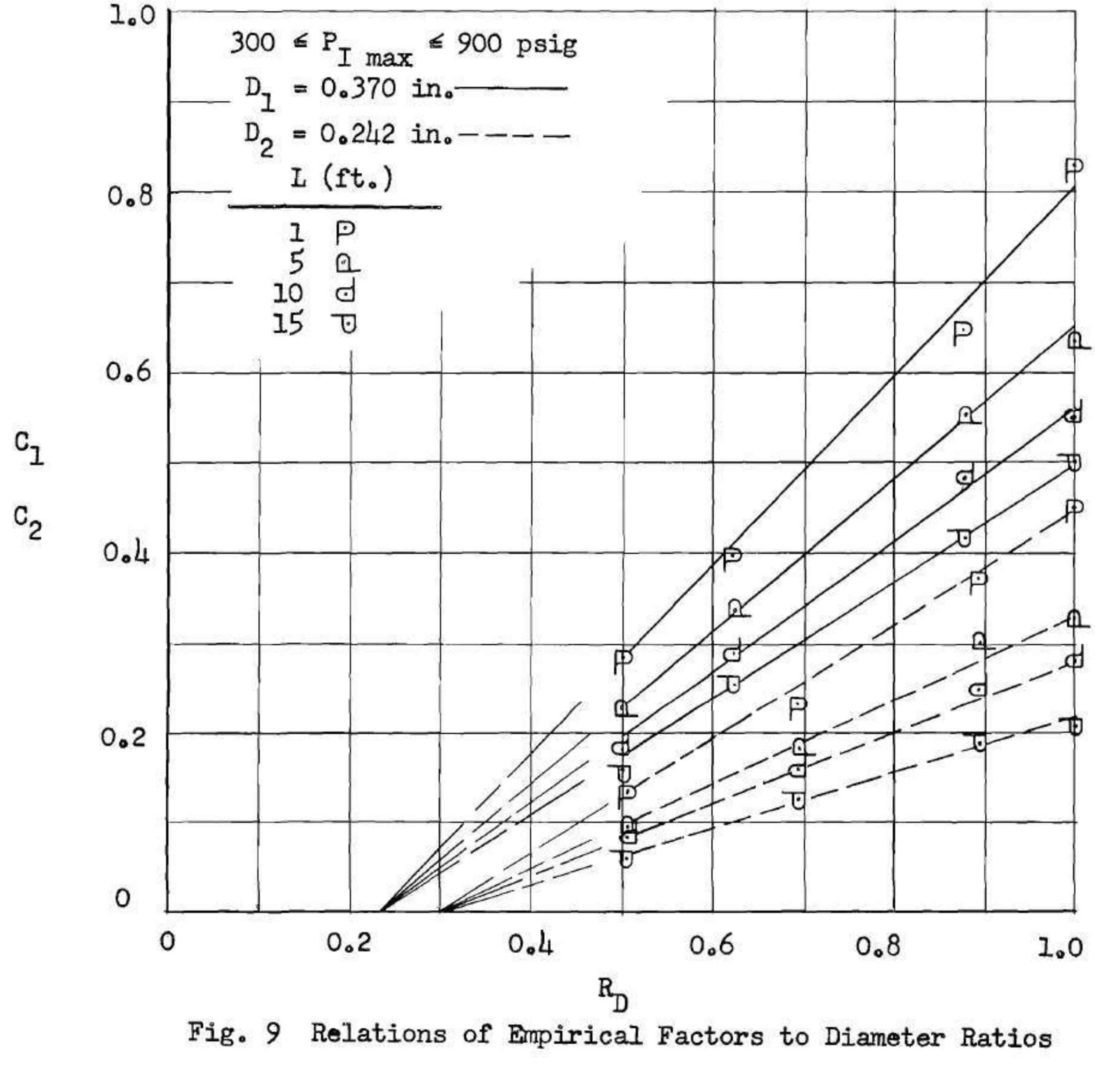

Fig. 9 Relations of Empirical Factors to Diameter Ratios

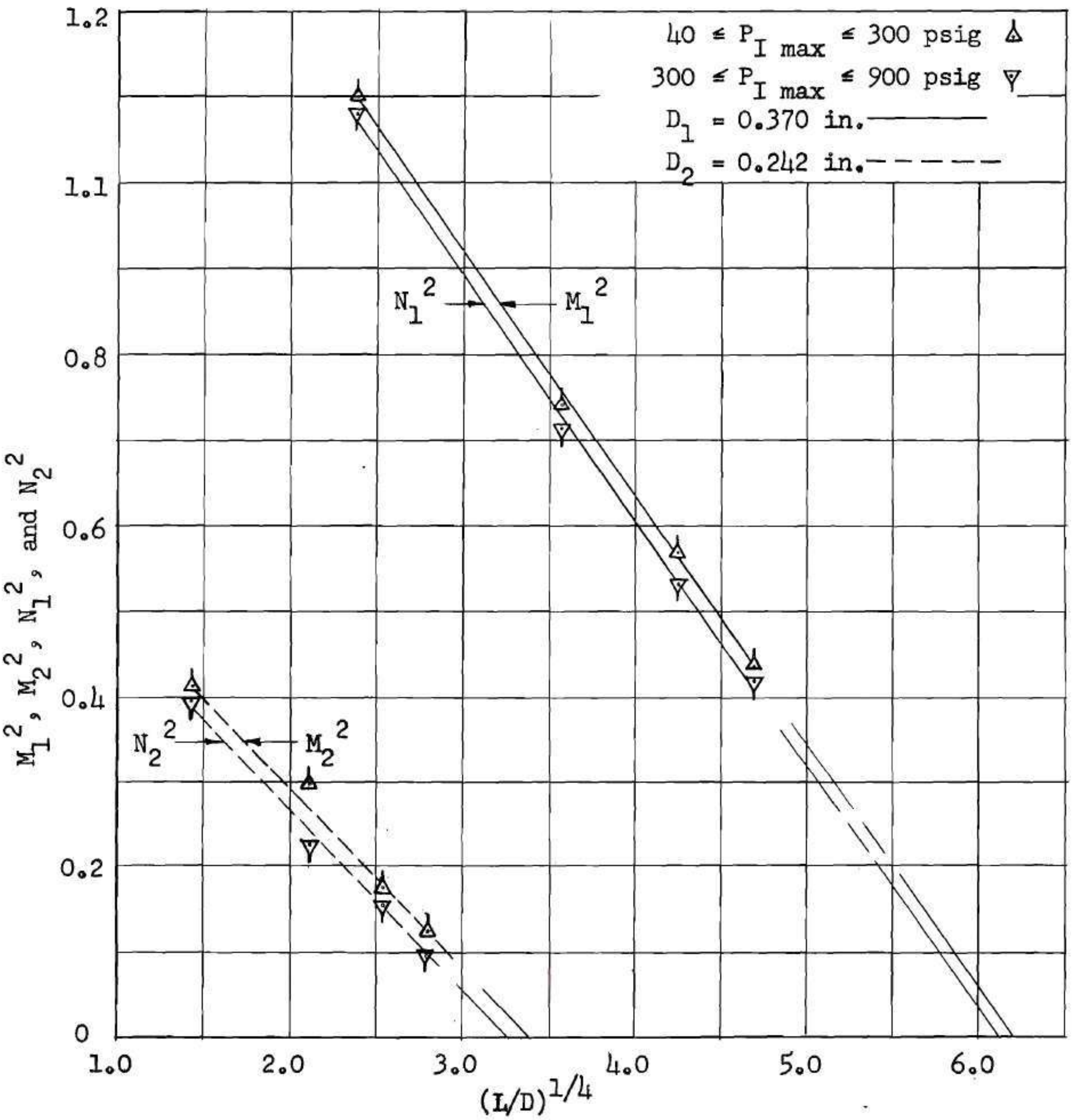

Fig. 10 Relations of Empirical Factors to L/D

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